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THE USE OF PRIMERS IN THE ADHESIVE BONDING OF CARBON-FIBRE REINFORCED COMPOSITES

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SUMMARY

The effect of priming carbon-fibre reinforced composite on adhesive-bonded joints has been studied by comparing joint strengths, bondline void contents and modes of failure for primed and unprimed composite.

Six epoxy film adhesives were used with their recommended primers.

In general, the use of a primer had very litte effect on bonded joints. From the changes in mode of failure, it was possible that primers had improved adhesion between composite and adhesive. In one case, the use of primer resulted in increased bondline void contents, reduced strengths and plasticisation of the adhesive. GREAT BRITAIN. (355) <=

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LIST OF CONTENTS

1 INTRODUCTION

Primers are commonly employed in structural adhesive bonding of metals, their main function being to protect the metal surface after pretreatment.

There are two main types of primer. Surface protection coatings are generally dilute solutions of adhesive base resin intended to protect the surface from damage or contamination during storage when bonding is not carried out immediately after pretreatment. They typically require only drying at room temperature or 70°C to remove solvent.

The second type is the corrosion-inhibiting primer which contains chromate salts for the inhibition of electrolytic corrosion of aluminium alloys and which requires curing at 120°C.

Oxide films formed on aluminium surfaces by chemical pretreatment can be susceptible to mechanical damage and contamination by, for example, greasy finger marks. The durability of an adhesive-bonded joint depends on having a clean surface of constant, consistent morphology.

In contrast carbon-fibre composite surfaces are pretreated for bonding by abrasion to remove surface contaminants such as mould release agents[1,2]. It is the practice of Adhesives Section, RAE, to wipe bonding surfaces with a tissue soaked in a solvent such as acetone or methyl ethyl ketone immediately before applying adhesive to the surface. Although primarily intended to remove any debris left after abrasion, this solvent wipe should also remove grease and other contaminants deposited after abrasion.

The main contaminant of stored epoxy resin carbon-fibre composite is absorbed water[3]. An epoxy primer layer would also absorb moisture and would not, therefore, give any protection against such contamination. It is impossible for an organic material like carbon-fibre composite to corrode like a metal. Thus there seems to be no need to use corrosion-inhibiting primers.

Only one primer is actually recommended for use with carbon-fibre composites[4]. This is intended to protect painted composite surfaces against paint strippers. However it is known that some companies do routinely prime carbon-fibre composite surfaces and it has been claimed[2] that the use of primer can enhance cohesive bond strength.

There are mechanisms by which it could be possible for a primer to improve the adhesive bonding of composites. Surfaces which have been pretreated by dry grit blasting can be very rough[2], with fractured resin and broken fibres. It has

been suggested that surface roughness may be a cause of voiding in bondlines[5]. Primers, which are low viscosity solutions of resins, might increase joint strengths by reducing roughness and hence voiding, or by healing cracks in the matrix resin which might not be filled by a higher viscosity adhesive and which might therefore act as crack initiators under stress.

In this work, carbon-fibre reinforced epoxy resin composite was bonded with six epoxy resin film adhesives with and without their recommended primers, details of which are given in Tables 1 and 2. Single-lap joint strengths were measured at ambient temperature and at 80°C on nominally dry joints and after exposure to 50°C/96% RH. Modes of failure and bondline void contents were estimated.

2 EXPERIMENTAL

2.1 Composite preparation

Unidirectional carbon-fibre reinforced laminates were prepared from Fibredux 914C/XAS prepreg by autoclave moulding. Laminates, which were nominally 2 mm thick, were cut into panels 300 mm wide × 100 mm in the fibre direction and were then stored either in a desiccator cabinet over silica gel or in an air-circulating oven at 70°C.

In view of the known effect of water at the composite surface on certain adhesives[3], records were kept of the weights of composite panels. Those which were stored in a desiccator between preparation and priming tended to gain weight during storage by water absorption due to inadequate desiccation.

In the first series of joints prepared with adhesives B, K and L, the pair of panels which were unprimed were estimated to contain more water than those which were primed even though, as with adhesive K/composite batch XM, the panels had been partially dried before bonding. While the moisture they still contained was probably concentrated towards the centre of the laminate and was not therefore likely to affect bonding, it was decided that all other unprimed panels should accompany primed panels through the primer drying/curing cycle to try to ensure the same laminate surface water content.

Estimated water contents at bonding are given in Tables 3 to 8. Except for the panels mentioned in the previous paragraph, water content was due to absorption during up to three days storage between priming and bonding.

2.2 Priming

Primer solutions were applied to composite panels along the pretreated bonding edges only using a 1 inch wide squirrel-hair brush.

Manufacturer's data sheets give the amount of primer to be applied either as a given film thickness (American products) or as a coating weight per unit area (British products). In the latter case, one is instructed to 'apply a light continuous coating, enough to ensure complete coverage ... but not enough to give a pronounced colour; aim to achieve the lightest coating that will just cover the surface'. It is implied that the ideal coating weight is 5 g/m^2, between limits of 2 g/m^2 and 12 g/m^2.

Equipment for measuring non-conducting film thickness on metal surfaces does not work on carbon-fibre composites. While for metals it is possible to produce colour standards to calibrate coating weight, this again is not possible on black composite.

Preliminary experiments were carried out using two primers on chromic-sulphuric acid etched aluminium strips. Aluminium was used to obviate complications due to possible loss of water from the composite and so that the evenness of the layer of primer could be judged visually. [All primers were coloured.] The brush was dipped in primer solution and excess liquid removed by drawing the brush across the edge of the beaker. The loaded brush was then drawn along the aluminium strip. This was done once, twice or four times before the primer was dried or cured. The aluminium strips were weighed before and after use.

Results are:

Number of passes of brush	Primer P1	Primer P2
1	1.50 g/m^2	1.2 g/m^2
2	1.50 g/m^2	1.4 g/m^2
4	2.80 g/m^2	

On this basis, it was decided that two passes of the brush would give a light coverage and yet allow gaps left in the first layer to be filled on the second pass.

In one case (K/batch XR), an even lighter coating was achieved by diluting the primer solution with methyl ethyl ketone before application.

All primed laminates were weighed before priming and after drying/curing. The area covered by primer was estimated and the coating weight calculated.

2.3 Joint preparation

The adhesives and primers and their cure schedules are given in Tables 1 and 2 respectively. Panels are bonded together to form single-lap joints with approximately 12 mm overlap. After bonding, panels were cut to give joints approximately 25 mm wide. Joint widths and overlaps were measured.

2.4 Joint testing

Dry joints were tested in tension at room temperature (20-24°C) and at 80°C, using a cross-head speed of 1 mm min^{-1}. Failure loads were recorded.

For all adhesives except L, joints were also exposed for 1000 hours at 50°C/96% RH before testing.

Broken joints were examined under a microscope (approximately ×10 magnification). The area of voids visible was estimated. The relative area, excluding voids, of each of the following possible modes of failure was also estimated:

- failure in the composite
- failure at the composite - adhesive interface
- failure in the adhesive.

3 RESULTS

Results are given in Table 3 for adhesive B and primers P1 and P2, in Table 4 for adhesive J and primer P3, in Table 5 for adhesive K and primer P4, in Table 6 for adhesive L and primer P5, in Table 7 for adhesive M and primer P6, and in Table 8 for adhesive R and primer P7.

Each Table gives details of the thermal history of each batch of composite prior to priming and bonding, the estimated water content, average joint strengths and modes of failure at ambient temperature and at 80°C, and the void content averaged over joints tested at both temperatures, and, for sets which were exposed, over both wet and dry joints.

Normally five joints were tested in each set. In some sets joints were excluded from the calculations due to processing faults such as over-thick

bondlines and excessive void contents. Estimated standard deviations are given where the average was taken over three or more joints.

4 DISCUSSION

4.1 Effect of priming on individual systems

4.1.1 Adhesive B with primers P1 and P2

As can be seen from the data in Table 3, joint void contents were generally low and were not related to the estimated water contents of the laminates at bonding.

The use of a primer did not generally lead to any substantially significant change in joint strength: while the average ambient joint strengths for composite XN were higher when primed, variability was high due to rather thick bondlines.

When tested at 20-24°C, both primed and unprimed joints tended to failure very largely in the composite, with some joints, especially those of composite XN, showing small areas of interfacial failure.

However, when tested at 80°C the proportion of failure observed in the composite was reduced and the proportions of failure in the adhesive and at the interface increased. The increase in failure at the interface was particularly large for unprimed joints of composite XN which had not been thoroughly dried before bonding. This effect may therefore be due to water present in the composite interfering with bonding reactions between adhesive and composite. This has been observed previously with this adhesive[3]. The smaller areas of interfacial failure observed in primed joints could be the result of reduced surface moisture content resulting from the primer drying/curing cycles or of the primer giving better bonding between composite and adhesive. Joints of composite KB, which contained far less water, showed very little interfacial failure unprimed and virtually none when primed. Comparison with joints of composite XN suggests that laminate moisture content may have had a greater effect than did priming.

After exposure to 50°C/96% RH, strengths of both unprimed and primed joints were reduced by about the same percentage: increased proportions of interfacial failure were observed at both test temperatures though the 120°C cured primer P2 showed only a small increase at 80°C.

The use of a primer may therefore result in slightly better bonding between adhesive and composite.

4.1.2 Adhesive J with primer P3

The results for this combination are given in Table 4.

The use of a primer with composite XP apparently resulted in a significant reduction in bondline void content. However, since there was no significant difference in void area between primed and unprimed joints of composite KD which had been more thoroughly dried, it is probable that the effect was again due to laminate water content rather than the primer.

Joints of composite XP were significantly stronger at both test temperatures when primed/dried at 120°C. While primed joints of composite KD were also stronger at room temperature when dry, at 80°C and after hot-wet exposure there was no significant difference in strength.

Most joints showed some interfacial failure, but the areas were small and did not vary markedly with test temperature, whether primed or not, or whether joints had been exposed to high humidity.

Joint strengths and areas of interfacial failure were higher than had previously been observed with this adhesive[3].

The use of primer P3 does not appear to have any advantage with adhesive J on composites.

4.1.3 Adhesive K and primer P4

As can be seen from Table 5, the use of a primer perhaps resulted in a small reduction in bondline void content. It can also be seen that the presence of water in the laminates, at the levels estimated here, had no effect on joint void content or on joint strength.

Due to high variability, there was generally no difference in room temperature or 80°C joint strength between primed and unprimed joints.

The only observable differences between primed and unprimed joints were in their modes of failure. Unprimed joints tended to show some interfacial failure between adhesive and composite, although for joints of laminate KE this was only at 80°C. In contrast only two out of 40 primed joints showed any interfacial failure. For laminate KE joints only, primed joints showed significantly less failure in the adhesive at 80°C, which may be an indication of better bonding.

4.1.4 Adhesive L with primer P5

The results in Table 6 show no difference between primed and unprimed joints. The marginal increase in strength at 80°C over room temperature is characteristic of this rather brittle adhesive.

4.1.5 Adhesive M with primer P6

The data for this combination are given in Table 7.

Joints of composite XT showed increased average void content when primed which was associated with a significant decrease in room temperature joint strength and a higher proportion of failure in the adhesive at both test temperatures. This implies that the primer was plasticising the adhesive.

Although the increase in void content observed for joints of laminate KE as a result of priming was not statistically significant, the decreases in joint strength were. For this composite, increases in proportions of failure in the adhesive were accompanied by significant decreases in observed interfacial failure, particularly after hot-wet exposure.

4.1.6 Adhesive R with primer P7

The data in Table 8 show that priming did nothing to reduce the high void contents observed with this adhesive.

Although the room temperature strengths of primed joints were on average higher, the differences were not significant due to high variability.

No joints showed any interfacial failure. Primed joints may have possibly shown rather more failure in the adhesive at room temperature, but again variability was such that the difference from unprimed joints was not significant.

4.2 Overall effects of priming

4.2.1 Effect on joint void content

In general the use of a primer did not have any significant effect on bondline void contents. All the adhesives used contained carrier cloths and it is probable that voiding is associated with these rather than with surface roughness of the composite.

In two cases (adhesive J/composite XP and adhesive K/composite KE), void contents were significantly reduced by the use of primer. However, in the former case, this was likely to have been the result of the primed composite having a

lower water content at bonding. For adhesive M, the use of primer resulted in an increased void content in the bondline.

4.2.2 Effect on joint strength

The only definite effects of priming on joint strength were noted for adhesives J, K and M, though not for all composite batches.

For adhesive M, reduced joint strengths may have been associated with increased bondline void contents. With adhesive K, joints of composite KE tested at 80°C showed increased strength: this set of joints also had reduced void content. Priming also resulted in increased joint strengths for adhesive J with composites XP and KP; however, in the former case this may have been associated with the higher water content of the unprimed composite.

4.2.3 Effect on mode of failure

With joints of adhesives B and K, the changes in mode of failure suggested that priming had improved adhesion between composite and adhesive, with decreased areas of interfacial failure being observed. For adhesive K and composite KE, improved adhesion seems to have resulted in increased failure in the composite.

On the other hand the joints of adhesive J and composite XP where dry and primed showed increased areas of interfacial failure.

Primed joints bonded with adhesive M showed reduced proportions of failure in the composite when tested at ambient temperature. It is thought that this might be the result of plasticisation of the adhesive by the primer: the increased void content with primed joints may indicate that the primer cure schedule of 1 hour at 120°C did not in fact remove all solvent, although the only declared solvent is methyl ethyl ketone.

4.2.4 Effect on environmental resistance

All joints lost strength after exposure to 50°C/96% RH for 1000 hours. However the effects of exposure tended to be the same for primed and unprimed joints.

5 CONCLUSIONS

The effect of using epoxy primers on carbon-fibre reinforced epoxy composites on adhesive bonded joints has been studied for a range of 120°C and 175°C cured epoxy adhesives. Each was used with its recommended primer. Some primers were protective coatings dried at 70°C and others corrosion-inhibiting

primers cured at 120°C. Joint properties were compared between primed and unprimed joints.

All joints were bonded within three days of priming so that any possible protective properties of primers were not investigated. However it is difficult to envisage primers having any effect against the main contaminant of stored CERP, which is absorbed water.

While it has been postulated that primers might reduce bondline void contents by reducing the roughness of pretreated composite surfaces, this was not found to be the case. Where void contents were reduced, it was more likely that this was due to the removal of absorbed water during the primer drying cycle: voids tend to be associated with vapour trapped in interstices of the carrier cloths in the adhesive film. In one case (adhesive M, primer P6), void contents were actually increased by the use of primer. Other changes in joint strength and mode of failure with this system suggested that there might have been plasticisation by residual solvent.

The one effect of primers was, in several cases, to reduce the amount of apparent interfacial failure in the joints or to increase the proportion of failure in the composite.

Primers generally had no effect on joint strengths at ambient temperature or at 80°C, both initially or after exposure to hot-humid conditions.

Table 1

ADHESIVES

Identification letter	Description	Cure schedule	Primers
B	Unsupported high strength modified epoxy film	½ hour 120°C	P1,P2
J	Epoxy nitrile film with random polyester mat carrier	1 hour 120°C	P3
K	High strength modified epoxy film, unsupported	1 hour 170°C	P4
L	High strength modified epoxy film with woven nylon carrier	1 hour 175°C	P5
M	Modified epoxy film with open knit nylon carrier	1 hour 120°C	P6
R	High temperature resistant modified epoxy structual film with woven nylon carrier	1 hour 175°C	P7

Table 2

PRIMERS

Identification letter	Description	Drying schedule
P1	Surface treatment protection solution (epoxy resin)	20 min at 70°C
P2	Corrosion and fluid resistant bonding primer (epoxy resin)	Air dry 15 min + 30 min at 70°C + 1 hour at 120°C
P3	Corrosion-inhibiting primer (modified epoxy phenolic resin)	Air dry 30 min + 30 min at 121°C
P4	Surface treatment protection solution (epoxy resin)	20 min at 70°ç
P5	Surface treatment protection solution (epoxy resin)	30 min at 70°C
P6	Corrosion-inhibiting solution (epoxy resin)	30 min air dry + 40-60 min at 120°C
P7	Surface pretreatment protection solution (epoxy resin)	30 min at 70°C

Table 3

STRENGTHS AND MODES OF FAILURE OF JOINTS BONDED WITH ADHESIVE B WITH AND WITHOUT PRIMERS P1 AND P2

Composite batch	Primer weight (g/m^2)	Test condition	Prebond composite water content (%)	Joint void content (%)	Tested at 20-24°C				Tested at 80°C			
					Joint strength (MPa)	Failure mode (% area)			Joint strength (MPa)	Failure mode (% area)		
						Composite	Interface	Adhesive		Composite	Interface	Adhesive
XN	Nil (1)	Dry	0.022	3 ± 2	40.0	97	1	1	28.7 ± 0.8	7 ± 3	83 ± 8	10 ± 6
	P1,1.5		0.018	4 ± 3	41.5 ± 3.8	95 ± 4	1 ± 1	4 ± 4	29.4 ± 1.1	32 ± 22	4 ± 5	64 ± 21
	P2,1.7		0.026	3 ± 3	43.1 ± 3.6	90 ± 10	10 ± 10	1 ± 0	30.3 ± 1.6	45 ± 17	27 ± 18	25 ± 13
XB	Nil (2)	Dry	0.005	4 ± 4	41.3	99	0	1	33.2	67	2	31
	P1,2.1		0.003	5 ± 2	43.2 ± 1.0	89 ± 9	0 ± 1	11 ± 9	30.1 ± 2.0	44 ± 12	0	56 ± 12
	Nil (3)		0.006	5 ± 4	40.7	93	1	6	28.9	71	3	26
	P2,2.2		0.006	4 ± 3	40.0 ± 1.6	98 ± 3	0	2 ± 3	29.5 ± 1.3	41 ± 15	0	59 ± 15
	Nil (2)	After 1000 h at 50°C/ 95% RH		as above	38.8	85	13	3	27.8	9	28	64
	P1,2.1				41.2 ± 0.6	89 ± 9	3 ± 3	9 ± 6	28.0 ± 1.2	24 ± 13	16 ± 12	60 ± 20
	Nil (3)				40.7	93 ± 1	4 ± 3	3 ± 2	28.3 ± 2.4	16 ± 5	47 ± 14	34 ± 22
	P2,2.2				38.6 ± 1.1	98 ± 1	0	2 ± 1	28.3 ± 1.5	25 ± 13	3 ± 7	71 ± 15

Composite batch conditioning before bonding:

XN Stored in desiccator cabinet for 2 months then dried overnight at 70°C. Water absorbed during storage (see 2.1).
XB Stored in desiccator cabinet for 6 weeks then dried overnight at 70°C. Assumed dry as weight increased by 0.0005 g after (2) and (3). Water content due to storage after priming.

Notes: (1) Unprimed composite not further dried.
(2) Unprimed composite dried by primer P1 cure cycle.
(3) Unprimed composite dried by primer P2 cure cycle.

Table 4

STRENGTHS AND MODES OF FAILURE OF JOINTS BONDED WITH ADHESIVE J WITH AND WITHOUT PRIMER P3

Composite batch	Primer weight (g/m^2)	Test condition	Prebond composite water content (%)	Joint void content (%)	Tested at 20-24°C				Tested at 80°C			
					Joint strength (MPa)	Failure mode (% area)			Joint strength (MPa)	Failure mode (% area)		
						Composite	Interface	Adhesive		Composite	Interface	Adhesive
XP	Nil (1)	Dry	0.02	27 ± 10	33.3 ± 1.9	2 ± 1	0	98 ± 1	18.6 ± 2.3	1 ± 1	3 ± 3	96 ± 3
	0.6		0	16 ± 7	37.2 ± 1.5	2 ± 1	2 ± 2	95 ± 4	23.8 ± 2.5	1 ± 0	10 ± 6	90 ± 7
KD	Nil (2)	Dry	0.007	20 ± 7	33.6 ± 1.1	10 ± 6	4 ± 5	86 ± 9	20.8 ± 1.3	16 ± 10	8 ± 9	76 ± 10
	0.6		0.008	18 ± 8	37.7 ± 1.1	9 ± 6	1 ± 1	89 ± 6	21.3 ± 0.7	15 ± 9	7 ± 10	78 ± 12
	Nil (2)	After 1000 h at 50°C/ 95% RH		as above	31.9 ± 2.8	11 ± 3	2 ± 3	87 ± 5	17.7 ± 1.7	70 ± 10	1 ± 4	29 ± 8
	0.6				31.5 ± 1.6	17 ± 12	0 ± 1	83 ± 11	18.0 ± 1.4	49 ± 27	1 ± 4	50 ± 26

Composite batch conditioning before bonding:

XP Stored 2 months at 70°C. Water content is uptake during storage for unprimed composite (see section 2.1), primed composite assumed to be dry.

KD Stored 1 week in desiccator cabinet and 2 days at 70°C. Water content due to storage after priming.

Notes: (1) Unprimed composite not further dried.
(2) Unprimed composite dried by primer cure cycle.

Table 5

STRENGTHS AND MODES OF FAILURE OF JOINTS BONDED WITH ADHESIVE K WITH AND WITHOUT PRIMER P4

Composite batch	Primer weight (g/m^2)	Test condition	Prebond composite water content (%)	Joint void content (%)	Tested at 20-24°C				Tested at 80°C			
					Joint strength (MPa)	Failure mode (% area)			Joint strength (MPa)	Failure mode (% area)		
						Composite	Interface	Adhesive		Composite	Interface	Adhesive
XM	Nil (2) 0.3 (3)	Dry	0 0	23 ± 4 19 ± 7	42.4 ± 2.5 38.4 ± 3.7	92 ± 5 77 ± 21	2 ± 3 0	5 ± 2 23 ± 21	30.8 ± 0.7 29.1 ± 2.6	20 ± 6 18 ± 16	21 ± 16 0	57 ± 14 82 ± 16
XR	Nil (1) 3.0	Dry	0.079 0	16 ± 5 13 ± 4	41.8 ± 2.2 43.3 ± 1.8	78 ± 9 83 ± 6	1 ± 3 0	21 ± 8 19 ± 6	30.6 ± 1.4 30.9 ± 0.9	29 ± 19 33 ± 16	5 ± 11 0	64 ± 17 67 ± 16
KE	Nil (2) 2.8	Dry	0.008 0.006	29 ± 11 20 ± 7	42.2 43.8 ± 2.0	80 96 ± 6	0 0	21 4 ± 6	25.4 31.1 ± 1.0	40 69 ± 8	2 1 ± 3	58 30 ± 8
	Nil (2) 2.8	After 1000 h at 50°C/ 95% RH		as above	34.9 ± 2.2 38.3 ± 3.7	75 ± 12 97 ± 2	0 0	25 ± 12 3 ± 2	22.8 ± 1.6 24.9 ± 3.0	21 ± 5 58 ± 24	0 0	79 ± 5 42 ± 24

Composite batch conditioning before bonding:

XM Stored in desiccator cabinet for 1 week. Assumed to be dry after (2).
XR Stored in desiccator cabinet for 2 months, dried at 107°C for 16 hours, 2 days at 90°C then 3 hours at 70°C. Unprimed panels had gained weight during storage; panels for priming lost weight and were assumed to be dry.
KE Stored in ambient for 1 week then 7 days at 70°C. Water absorbed during storage overnight after priming.

Notes: (1) Unprimed composite not further dried.
(2) Unprimed composite dried by primer cure cycle.
(3) Primer diluted to approximately 50% volume with methyl ethyl ketone.

Table 6

STRENGTHS AND MODES OF FAILURE OF JOINTS BONDED WITH ADHESIVE L WITH AND WITHOUT PRIMER P5

Composite batch	Primer weight (g/m^2)	Test condition	Prebond composite water content (%)	Joint void content (%)	Tested at 20-24°C				Tested at 80°C			
					Joint strength (MPa)	Failure mode (% area)			Joint strength (MPa)	Failure mode (% area)		
						Composite	Interface	Adhesive		Composite	Interface	Adhesive
XT	Nil (1) 2.3	Dry	0 0	14 ± 9 11 ± 5	20.2 ± 1.0 19.5 ± 0.6	97 ± 2 97 ± 3	0 0	3 ± 2 3 ± 3	21.9 ± 2.2 20.6 ± 1.4	97 ± 3 97 ± 2	0 0	3 ± 3 3 ± 2

Composite batch conditioning before bonding:

XT Stored in desiccator cabinet for 5 months then dried for 305 hours at 70°C. Weight loss during primer cure cycle 0.002%. Assumed to be dry at bonding.

Note: (1) Unprimed composite dried by primer cure cycle.

Table 7

STRENGTHS AND MODES OF FAILURE OF JOINTS BONDED WITH ADHESIVE M WITH AND WITHOUT PRIMER P6

Composite batch	Primer weight (g/m^2)	Test condition	Prebond composite water content (%)	Joint void content (%)	Tested at 20-24°C				Tested at 80°C			
					Joint strength (MPa)	Failure mode (% area)			Joint strength (MPa)	Failure mode (% area)		
						Composite	Interface	Adhesive		Composite	Interface	Adhesive
XT	Nil (1) 2.2	Dry	0 0	8 ± 3 13 ± 5	45.9 ± 3.1 42.8 ± 1.9	48 ± 12 24 ± 14	12 ± 14 8 ± 10	44 ± 12 68 ± 8	33.8 ± 2.4 32.3 ± 0.9	59 ± 17 19 ± 19	30 ± 17 13 ± 14	11 ± 8 68 ± 32
KE	Nil (1) 2.0	Dry	0.010 0.011	11 ± 5 15 ± 7	42.7 ± 1.8 40.5 ± 0.9	50 ± 8 24 ± 14	9 ± 8 3 ± 2	38 ± 11 73 ± 13	29.1 ± 1.1 27.3 ± 1.5	16 ± 8 31 ± 31	52 ± 12 22 ± 20	32 ± 13 50 ± 25
	Nil (1) 2.0	After 1000 h at 50°C/ 95% RH			41.2 ± 1.8 38.7 ± 1.1	55 ± 13 37 ± 15	16 ± 7 3 ± 5	29 ± 13 59 ± 16	25.8 ± 2.4 24.2 ± 1.7	19 ± 10 35 ± 29	42 ± 24 9 ± 8	38 ± 27 56 ± 34

Composite batch conditioning before bonding:

XT Stored in desiccator for 5 months, then dried 305 hours at 70°C.
KE Stored for 2 weeks at 70°C. Water uptake during 1½ days storage between priming and bonding.

Notes: (1) Unprimed composite dried by primer cure cycle.

Table 8

STRENGTHS AND MODES OF FAILURE OF JOINTS BONDED WITH ADHESIVE R WITH AND WITHOUT PRIMER P7

Composite batch	Primer weight (g/m^2)	Test condition	Prebond composite water content (%)	Joint void content (%)	Tested at 20-24°C				Tested at 80°C			
					Joint strength (MPa)	Failure mode (% area)			Joint strength (MPa)	Failure mode (% area)		
						Composite	Interface	Adhesive		Composite	Interface	Adhesive
KG	Nil (1) 2.9	Dry	0 0	26 ± 11 24 ± 11	32.9 ± 2.4 33.6 ± 3.6	48 ± 28 29 ± 26	0 0	52 ± 28 71 ± 26	28.5 ± 2.6 27.7 ± 2.3	10 ± 19 2 ± 3	0 0	90 ± 19 98 ± 3
	Nil (1) 2.9	After 1000 h at 50°C/ 95% RH			32.8 ± 3.0 35.6 ± 4.0	34 ± 36 13 ± 9	0 0	66 ± 36 87 ± 9	21.5 ± 0.9 22.4 ± 2.2	1 ± 1 1 ± 0	0 0	99 ± 1 99 ± 0

Composite batch conditioning before bonding:

KG Stored at 70°C for 1 week. Assumed dry at priming.

Note: (1) Unprimed dried by primer cure cycle.

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17. Abstract

The effect of priming carbon-fibre reinforced composite on adhesive-bonded joints has been studied by comparing joint strengths, bondline void contents and modes of failure for primed and unprimed composite.

Six epoxy film adhesives were used with their recommended primers.

In general, the use of a primer had very little effect on bonded joints. From the changes in mode of failure, it was possible that primers had improved adhesion between composite and adhesive. In one case, the use of primer resulted in increased bondline void contents, reduced strengths and plasticisation of the adhesive.

ISSUE 1